TALLINN UNIVERSITY OF TECHNOLOGY
School of Information Technologies

Ali Tunahan Dabak IVEM156300

SMARTPHONE BASED GONIOMETRIC SOLUTION FOR TRAINING SAFETY MONITORING

Master's thesis

Supervisor: Alar Kuusik
PhD
Senior Researcher

Tallinn 2017

TALLINNA TEHNIKAÜLIKOOL
Infotehnoloogia teaduskond

Ali Tunahan Dabak IVEM156300

NUTIFONIL BASEERUV GONIOMEETRILINE LAHENDUS TREENINGU OHUTUSE JÄLGIMISEKS

Magistritöö

Juhendaja: Alar Kuusik
PhD
Vanemteadur

Tallinn 2017

Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

Author: Ali Tunahan Dabak

05.05.2017

Abstract

Nowadays a large percentage of the interest in Internet of Things is attributed to wearable technologies and wellness applications. The wearable motion sensing solutions and related smartphone applications have become accepted tools for conducting the clinical research. Also, such applications are suitable to obtain measurements during the professional clinical practice. The aim of this thesis is to develop a smartphone application that could assist patients during the home trainings with the help of wearables. The target user group is patients who need to perform recovery exercises of lower extremity joints during their rehabilitation program.

This thesis is written in English and is 64 pages long, including 8 chapters, 35 figures and 4 tables.

Annotatsioon

NUTIFONIL BASEERUV GONIOMEETRILINE LAHENDUS TREENINGU OHUTUSE JALGIMISEKS

Suur osa tähelepanust asjade internetile saab hetkel osaks kehal kantavatele sensortehnoloogiatele ja terviserakendustele. Kehal kantavad liikumisandurid ja seotud nutifonide rakendused on tunnustatud töövahendid kliinilistes uuringutes. Samuti on sellised rakendused sobivad mõõtmisteks professionaalses kliinilises töös. Käesoleva lõputöö eesmärgiks on välja töötada nutifoni rakendus, mis võimaldab abistada patsiente kodutreeningute ajal kantavaid sensoreid kasutades. Sihtgrupiks on patsiendid, kes peavad sooritama alajäsemete liigeste harjutusi oma rehabilitatsiooniprogrammi raames.

Lõputöö on kirjutatud inglise keeles ning sisaldab teksti 64 leheküljel, 8 peatükki, 35 joonist, 4 tabelit.

List of abbreviations and terms

TTU	Tallinn University of Technology
App	Application
ROM	Range of Motion
GATT	Generic Attribute Profile
IMU	Inertial Measurement Units
BLE	Bluetooth
UG	Universal Goniometer
UI	User Interface
JVM	Java Virtual Machine

Table of contents

List of figures

List of tables

1 Introduction

Day by day, technology is playing more important role in our lives. The Internet of Things (IoT) is gaining popularity across all industries. A large percentage of the interest in the IoT is attributed to wearable technology and wellness smartphone applications. Wearable technology generates a large amount of individual data, and datasets, which can be utilized to improve such things as precision medicine, preventive care and remote monitoring for healthcare rehabilitation. Doctors and physicians are embracing the use of medical wearable technology and wellness smartphone applications to assess medications, monitor trends, and adjust therapies based on behavioural patterns [1]. This will allow more quick and more accurate targeted treatments for faster patient recoveries. Besides that due to increase of healthcare costs, it would be useful to develop more advanced sensors/apps which reduce the needs of professional assistance and support patients outside of hospitals or clinics.

The thesis will focus on development of smartphone application based solution that can assist patients for home trainings, specifically patients who need perform exercises for limb joints.

2 Medical Wearables

The Internet of Things (IoT) describes the idea of everyday physical objects being connected to the Internet and being able to communicate and collaborate with the other devices. From the building automation, smart cities and smart factories the IoT touches all application fields. Analysts estimate that more than 50 Billion devices will get connected to the Internet by 2020 [2]. According to analyst firm CCS Insight, a large portion of these devices are medical wearables [3]. CCS Insight expects that wearables market is set to treble in size by 2019 and become worth over $25 Billion. Another research market IDTechEx, expects $150 Billion market size by 2026 as it can be concluded from Figure 1.

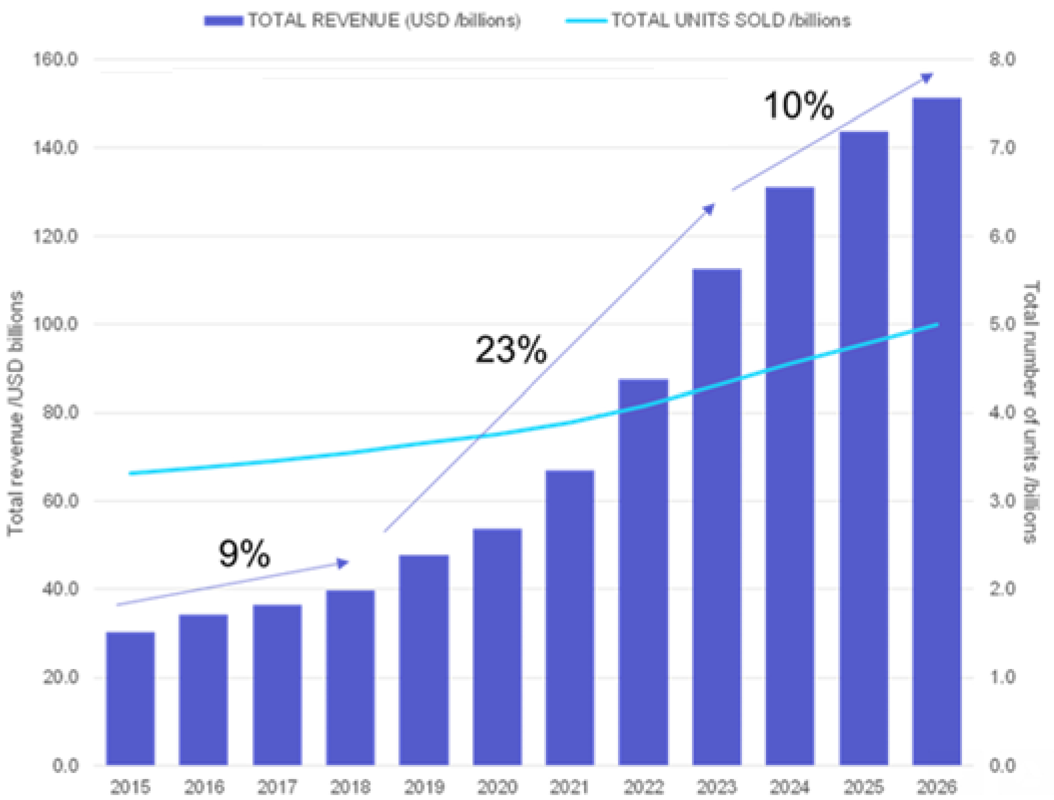


Figure 1 Relation between total revenue and total number of units [3]

It can be understood that one of the most rapidly evolving topics of the IoT is wearables. Some wearable medical devices and systems are presented in the following subchapter 2.1

2.1 Examples of Wearable Medical Devices

- **A Finger Ring**

The ring sensor is capable of reliably monitoring patient's heart rate and blood oxygen saturation (SO2) [4].The ring prototype contains an analog and digital processing unit, an optical sensor unit and radio transmitter. All of them are encapsulated in a compact body and powered by a tiny cell battery used for wristwatches as it can be seen in Figure 2.

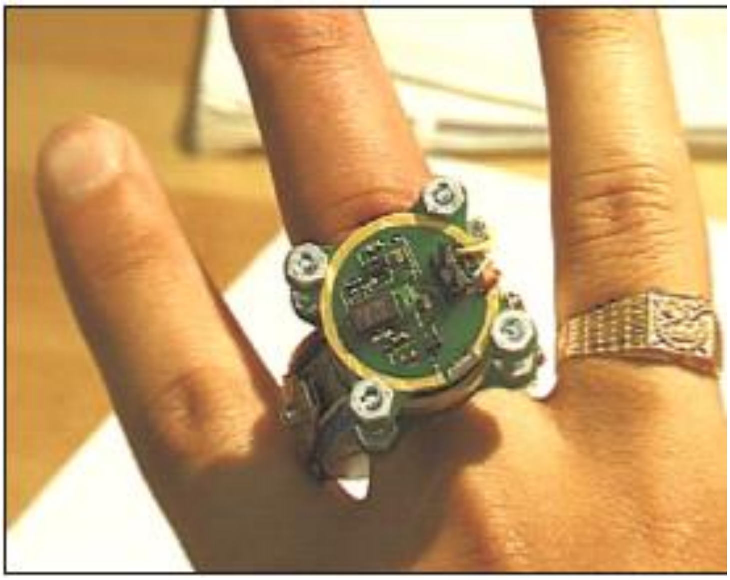


Figure 2 First prototype ring sensor

- **Gyro Glove**

This wearable medical device was developed by Faaii Ong, a researcher from Imperial College London, for patients who have Parkinson's disease [5]. According to the study, this device was the first wearable solution for reducing the hand tremors. Basically, the Gyro Glove fits on the back of the hand and uses dynamically adjustable gyroscope, as it can be seen in Figure 3.

The orientation of Gyro Glove is adjusted by a precession hinge and turntable, both controlled by a small circuit board, thereby pushing back against the wearer's movements as the gyroscope tries to right itself. In particular to studies, this early stage testing of the described wearable medical device has shown significant reduction of tremors of over 80%.

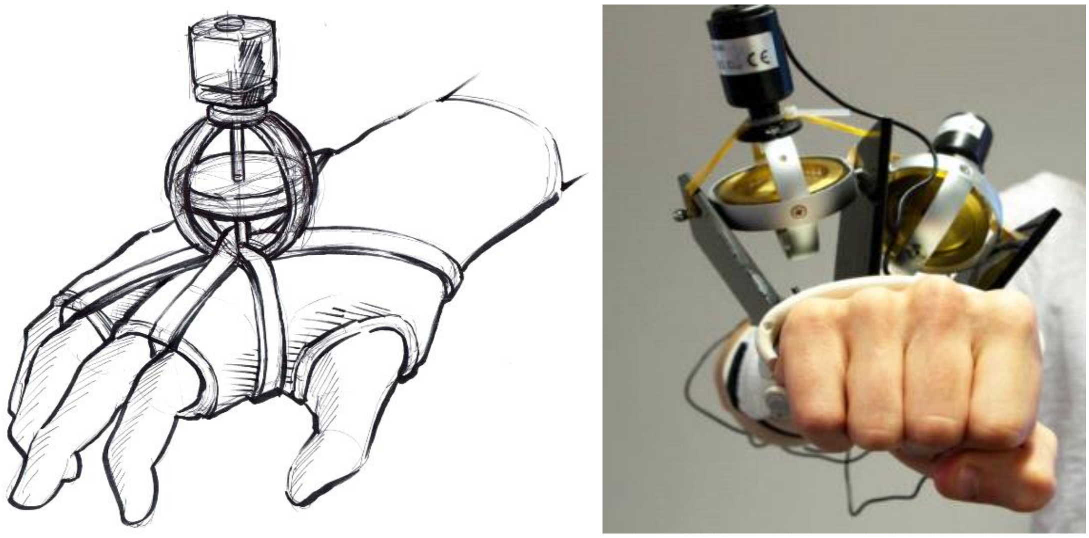


Figure 3 Gyro Glove Prototype

- **LG Earphones**

As it mentioned previously, wearable devices can be used also in the fitness market. LG Electronics has designed earphones that measure wearer's heart rate, as it can be seen in Figure 4 [6].

This device has been developed to provide accurate hear rate data by measuring blood flow signals in the ear via PerformTek, sensor technology that continuously measures heart rate and activity. To provide accurate data in real time the device also includes, a triple-axis accelerometer and an altimeter. This device communicates with the mobile app via Bluetooth 3.0.

Figure 4 LG Earphones

- **Bodymedia a Sense Wear Pro Armband**

The Body media Sense Wear Armband is a multi-sensor body monitor device, attached on the triceps of the arm, as shown in Figure 5 [7]. This wearable device allows continuous recording of physiological signals of the body such as skin temperature, heat flow, movement and galvanic skin response. The Sense Wear Pro Armband is able to measure and quantify the levels and duration of real metabolic physical activity, steps, sleep and lifestyle.

The device contains five different sensors. A two-axis accelerometer tracks the movement of the upper arm and contributes information about position of body. Sensitive thermistors are used to measure skin temperature and near-armband temperature.

A proprietary heat-flux sensor measures the amount of heat being dissipated by the body. Also as mentioned, the armband measures galvanic skin response which varies due to sweating and emotional stimuli. This wearable device widely used in cardiology, neurology, fitness, rehabilitation, and for the research.

Figure 5 Sense Wear Armband and shown on arm

- **Hexoskin Shirt**

Hexoskin is a wearable sport sensor shirt as shown in Figure 6 [8]. It is designed in Canada, and contains different integrated sensors such as activity sensor, respiration sensor and hear beat sensor. This shirt is used to measure and track several physiological parameters including heart rate, respiration rate, total energy expenditure and amount of steps. Hexoskin wearable technology allows real-time health monitoring with smart-phones and tablets using a Bluetooth connection. According to a study [9], this technology is well validated and reliable. The main application areas of this technology are sport and fitness environment, psychiatry, telemedicine, respiratory and cardiac health monitoring.

Figure 6 Hexoskin wearable technology

- **Witching's Blood Pressure Monitor**

Witching's Smart Blood Pressure Monitor in the Figure 7 is one of the first smartphone app-supported blood pressure meter in the world [10]. The cuff device is connected to handheld device through the Bluetooth. The app measures user's heart rate, blood pressure and also counts the steps that user take weekly using smartphone sensors. This app is also able to set the device to take three measurements and report the average, which is consistent with medical recommendations.

Figure 7 The Smart Blood Pressure Monitor

- **Xsens MVN Biomech**

Xsens is the leading innovator in 3D motion tracking technology and products [11]. Sensor fusion technologies of Xsens enable interaction between the physical and the digital world in applications such as health, sports, industrial control and stabilization, and 3D character animation.

The MVN Biomech is one of the trend products of Xsens, as it can be seen in Figure 8 [12]. The MVN Biomech system is designed to measure 3D kinematics everywhere, under any circumstance. Both hardware and software of the MVN Biomech systems ensure reliable and accurate human motion measurements. Tiny and special developed trackers capture the small twitches to high dynamic movements on-body. Dedicated signal pipelines take care of real-time and robust data connections. Its application areas are biomechanics research, rehabilitation research, sports science, virtual reality and human machine interaction.

According to the study [13], the proven MVN Biomech biomedical model and sensor fusion algorithms ensure the highest quality motion analysis. The study proves the validity of inertial sensor based motion capture system, Xsens MVN Biomech, against a camera-based motion capture system for the measurement of joint angular kinematics.

Figure 8 The MVN Biomech technology

Medical wearables is one the most highly evolving topic of the technology. From the described wearable medical devices and systems, it can be understood that they provide much easier and safer life. Also the users can perform exercises at home without a need of assistance of doctors or clinicians and meanwhile record the results.

3 Body Joint Flexibility Assessment

The goal of current thesis is to develop wearable sensor for patient joint flexibility assessment (static measurement) and training support (real-time use). The main focus is on knee monitoring solution but the technology shall be applicable for monitoring other limb and hip joints as well.

Rehabilitation training process is important for patients suffering joint pain, it is essential after injury or joint replacement surgery. Exercises suggested by surgeon or physical therapist can strengthen muscles of the patient, improve flexibility, and help to recover faster [14]. For example in according to the literature [15], after total knee replacement, the average Range of Motion (ROM) should be around 105°-110° for the majority of the patients. Based on literature survey, another opinion is that at least 90° of ROM is desirable for a good functional outcome [15]. These recovery exercises should be done in correct way to minimize the risk of injuries and maximize the training outcomes. Thus the joint movement tracking during the exercising is advisable.

3.1 Joint angle and Flexibility Measurements

Goniometer is the most widely used instrument by therapists and other medical professionals to assess a patient's joint flexibility range [16]. There are different types of goniometers. Goniometer may be mechanical, such as the standard Universal Goniometer (UG) or digital such as electro goniometers or digital inclinometers. Among the different goniometers available, the most widely used in clinical settings is the UG, as it can be seen in Figure 9.

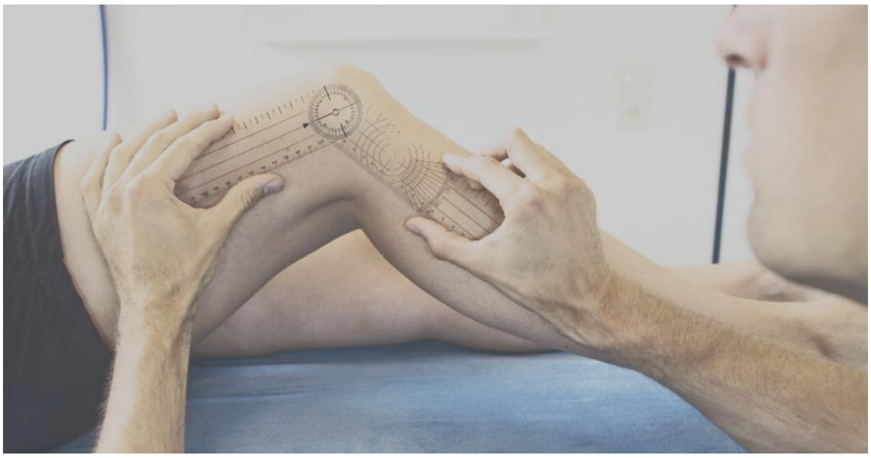


Figure 9 Example of standard goniometer

Recently, also smartphone goniometry apps have become available to medical and rehabilitation domains. According to literature review and several studies, these apps can be as reliable and accurate as goniometers [17]. One can simply open the app, place the phone to the correct position and perform the movements. The app will measure the range of motion that occurred around the specific joint. Some knee recovery exercises that patient can train at home while using goniometer based smartphone app can be seen in following Figure 10 [18]. These exercises can vary according to the specific need of the patient.

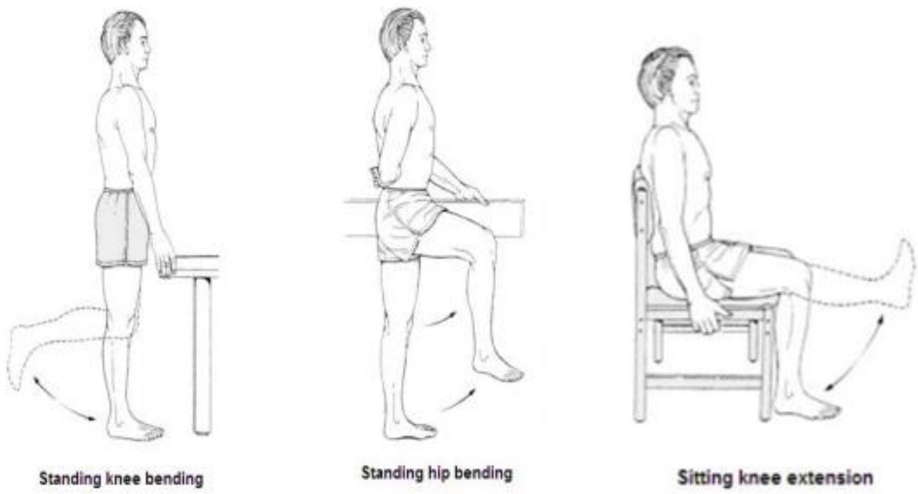


Figure 10 Some example exercises that can be monitored with goniometer app

Goniometer based smartphone apps have several advantages compared to traditional goniometers. A few to be listed:

- Simple and fast measurements because the devices are widely available;
- Patients can perform recovery exercises at home without a need of assistance of clinicians;
- Data can be accessed remotely;
- Faster measurements;
- Possibility to use several sensors;
- Possibility to transmit data directly to the patient's electronic health record in error-free way.

In the chapter 3.2 some existing smartphone apps for body angle measurements are explained in details.

3.2 Existing Smart-phone Apps for Body Position Measurement in Rehabilitation

In the last couple of years, several papers describing goniometric smartphone applications in rehabilitation have been published [17] [19]. Nowadays, as it was mentioned previously, goniometer apps are very useful because they are an alternative to the hand-held goniometers usually used in clinical practice.

In respect to different papers and studies published, following Table 1 is created to represent different existing goniometer smartphone apps. Each of these apps has different features, target areas, measurement methods and requires different operating systems.

App Name	Description	Method	Operating system
DrGoniometer [19]	This is the only app validated for photographic-based goniometry. Measurement is obtained by positioning a virtual goniometer, visible on the smartphone screen, on a photograph obtained via the smartphone camera. It is used to measure knee flexion.	Photographic based goniometric app	iOS
KneeGoniometer [20]	This app was developed to measure knee range of motion. Holding the smartphone on the patient's tibia one can measure tibial inclination using the app's inbuilt accelerometers.	Accelerometer based goniometric app	iOS
Clinometer [21]	This application is a slope finder tool that uses the 3-axis linear accelerometer of the smartphone. It has been validated to measure shoulder range of motion and cervical spine mobility.	Accelerometer based goniometry app	Android / iOS
Angle [22]	This app is validated for the measurement of knee range of motion. The tool displays the angle in relation to the horizontal plane by the use of inbuilt smartphone accelerometers.	Accelerometer based goniometry app	iOS

SimpleGoniometer [23]	This app uses the smartphone's internal accelerometers to measure joint angles by comparing the inclination of the segment above and below the joint.	Accelerometer based goniometry app	iOS
GetMyROM [24]	This app also is based on the iPhone's internal accelerometers. It works as a buble inclinometer.	Accelerometer based goniometry app	Android / iOS
Compass [25]	This app is based on magnetometer already integrated in the iPhone. The designed software measures cervical ROM on the horizontal plane	Magnetometer based goniometry app	iOS

Table 1 Existing different smartphone apps in respect to ROM measurement

According to the survey, there are 3 different sensing modalities to implement goniometric measurement with a smartphone. These are can be classified into three categories:

- Accelerometer-based apps
- Photographic-based apps
- Magnetometer-based apps

According to literature survey, in the following section, it has been explained some researches about validity and reliability of these modalities.

3.2.1 Photography-based goniometric apps

Photographic (also called photography-based, photograph-based) goniometry is one of the validated methods for goniometric measurement in rehabilitation. Photographic joint angle measurement uses an image to show the degree of joint motion limitation. In this measurement procedure, firstly, a picture of the joint is taken correctly according to a standard procedure. Then, a virtual goniometer should be placed on the picture using dedicated software.

The disadvantage of this method is that, it can be time consuming and the procedure can be complex to use for oneself but still, it has several advantages such as;

- It produces a physical and printable report (photo) in which investigators can make the measurements later;
- It does not require any contact with the skin;
- Can be simply integrated with PHR systems;
- It also can help to improve patient adherence to the treatment by visibly demonstrating the condition change.

DrGoniometer is one of the smartphone apps for body position measurement in rehabilitation. As it mentioned in Table 1, DrGoniometer is the only app, which is designed to measure the flexibility of knee by using photography-based goniometry.

There are some existing studies to assess the reliability of a smartphone based apps developed for photography-based goniometry. In respect to the measurement results of study [19], DrGoniometer is a reliable and validated method for knee joint angle measurement. In this app, the clinician or the user, takes a photo of the knee, saves it, then measures the joint angle and finally observes the value. Pictures must be taken with the camera positioned parallel to the body segment plane. Following Figure 11 show some examples of angular measurements made by DrGoniometer app.

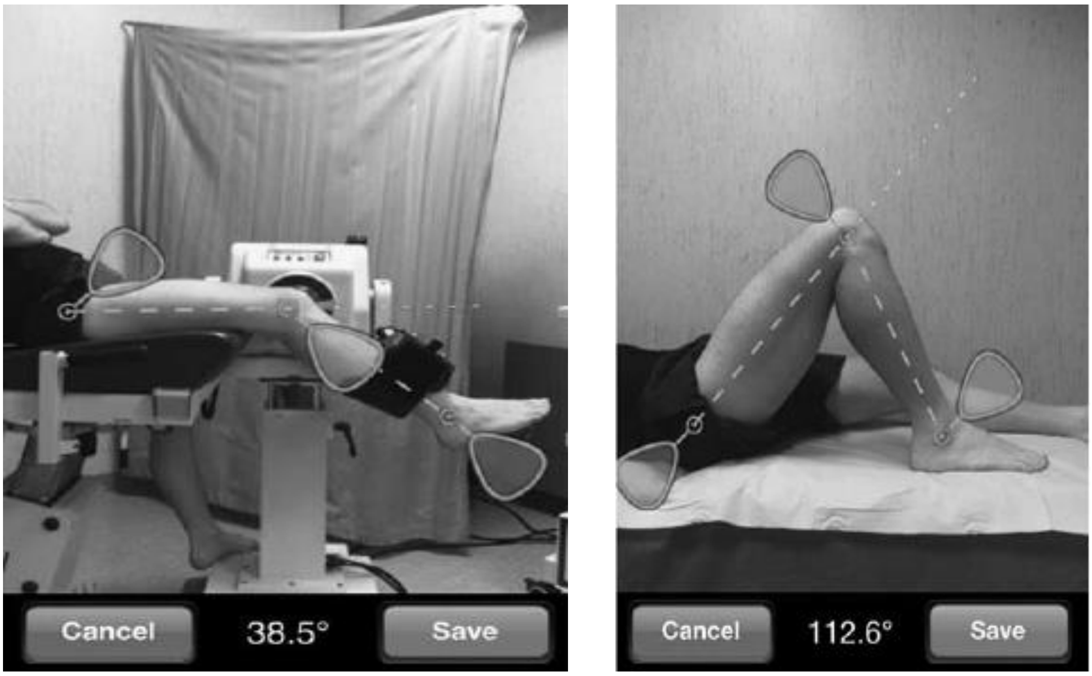


Figure 11 Angular measurements of the patient with different positions [19]

3.2.2 Magnetometer-based goniometric apps

Magnetometer is a device that measure magnetic fields. As it mentioned before, smartphones have numerous built-in sensors such as magnetometer, accelerometer and gyroscope. Magnetometer-based goniometric measurement uses the smartphone's magnetometer sensor, as the primary source, that make the phone capable of detecting position in space to help gather range of motion measurement.

According to the literature survey, there is currently limited research in the area of magnetometer based goniometry smartphone apps. It is not widely used method comparing to other methods. The research done by Linda B. Johnson is one of the first studies to evaluate performance of magnetometer based apps in goniometric measurement [26]. The aim of this research is to understand the validity and reliability of a smartphone magnetometer-based goniometer application by comparing against the universal goniometer (UG).

In this research, two devices were used for goniometric measurement of ROM in seated and supine positions. First device was UG and second device was an Android OS magnetometer-based goniometry smartphone app, which was developed by the University of California Berkeley.

In respect to study [26], first the UG placed over the ROM of shoulder and observed measurements, as it can be seen in Figure 12. Secondly, the magnetometer-based goniometric app used in similar manner. At the beginning, the smartphone is placed over closed arm and captured the position. Then, the smartphone is moved and placed over opened arm. Final position is captured and with the help of the smartphone app, the angle between two captured positions (starting and end points) is determined. Finally, the angle is displayed on the screen.

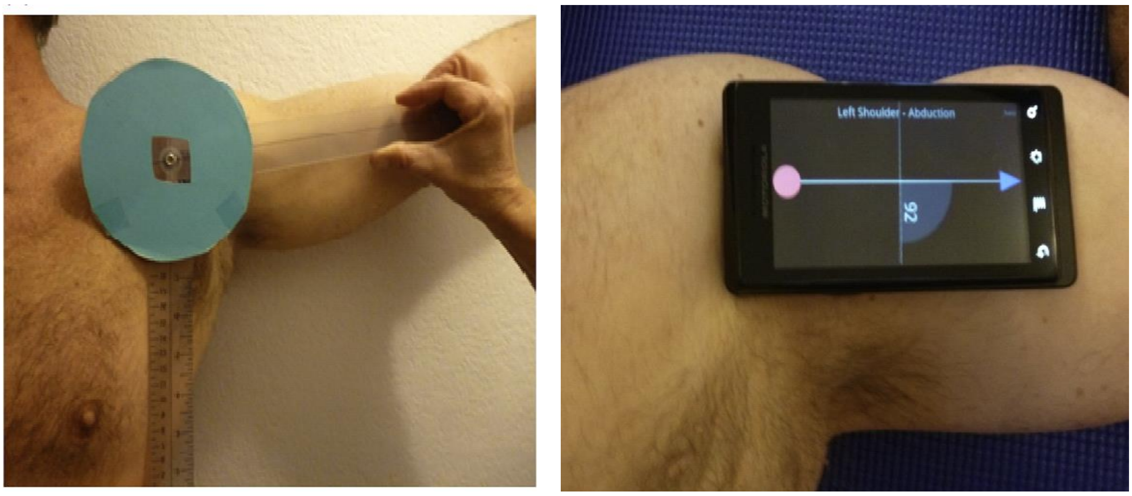


Figure 12 The UG used in the study [26] to make measurement and the reading from the application after data collection

Summary of measured angle data.

	Position	Location	Pre-determined joint angle (°)	Mean measured angle (°) ± SD			Total (°) ± SD
				Examiner 1 (n = 4)	Examiner 2 (n = 4)	Examiner 3 (n = 4)	
UG	Seated	1	105	105 ± 1	105 ± 1	98 ± 1	103 ± 4
		2	92	94 ± 1	94 ± 1	91 ± 2	93 ± 2
		3	40	41 ± 1	35 ± 1	38 ± 1	38 ± 3
		4	122	122 ± 1	115 ± 2	115 ± 2	117 ± 4
	Supine	1	35	35 ± 2	37 ± 1	35 ± 1	36 ± 2
		2	150	151 ± 2	152 ± 2	152 ± 1	152 ± 2
		3	58	58 ± 1	57 ± 3	69 ± 1	61 ± 6
		4	170	162 ± 1	165 ± 1	166 ± 2	164 ± 2
MG	Seated	1	105	106 ± 2	101 ± 2	106 ± 1	104 ± 3
		2	92	91 ± 1	93 ± 1	92 ± 6	92 ± 1
		3	40	37 ± 1	34 ± 2	34 ± 2	35 ± 2
		4	122	123 ± 1	123 ± 2	125 ± 1	124 ± 2
	Supine	1	35	35 ± 3	35 ± 2	32 ± 2	34 ± 3
		2	150	129 ± 2	151 ± 8	151 ± 5	143 ± 12
		3	58	48 ± 2	62 ± 7	69 ± 5	60 ± 10
		4	170	161 ± 3	169 ± 6	166 ± 4	165 ± 5

SD – standard deviation; n – sample size/number of trials.

Table 2 Measurement data from UG and magnetometer-based app [26]

In this study, the measurements were made with 3 different examiners in seated and supine positions. Table 2, represents the descriptive analysis and summary of data from both UG and magnetometer-based smartphone app. In respect to this study, the UG had an average standard deviation of ±4° in both seated and supine position. On the other side, magnetometer-based app showed an average standard deviation of ±2° in seated position and ±7.5° in the supine position.

According to measurements, there is not huge difference between two devices. The measurements in research study showed that the smartphone goniometer app utilizing a built-in 3 axis magnetometer sensor demonstrates the validity and reliability when it is compared against universal goniometer. Thus, it can be concluded that magnetometer based apps also can show potential as a useful tool to assess joint angles in vertical and horizontal orientations. But still, as it mentioned before, this method is not widely used and more complex to get precise measurements comparing to other modalities.

3.2.3 Accelerometer-based goniometric apps

Accelerometer-based goniometry is another validated and reliable method measurement in rehabilitation or in home training for recovery exercises.

According to the literature survey, this method is also the best and most useful one comparing to other goniometric measurement methods. In this measurement procedure, basically such apps are based on the use of an accelerometer, as the primary source, gyroscope and magnetometer sensors of the smartphone to analyse human movements and transform the measurements into quantitative values to provide precise reading of the ROM of different body part such as knee, elbow or shoulder.

According to the survey, there are numerous researches about accelerometer based goniometric apps. From these researches, it can be concluded that the use of accelerometer based goniometric app as an assessment tool, has been gaining ground in the health field due to its usability, validity and lack of technical difficulties.

Researches [27] and [28] are one of the first studies that prove the reliability and validity of accelerometer-based goniometric apps for ROM measurement of human body. Research [28] is based on validation of knee ROM measurement using accelerometer-based ROM app for Samsung Galaxy smartphone. In respect to this study, 34 different participants were measured by three trained examiners on two different days at the Physical Therapy Teaching Clinic of the Central West State University, Brazil. In this study, the participant was placed in the supine position with the hip and knee of the dominant limb flexed at 90° to measure the angle of knee flexion, as it can be seen in Figure 13.

Figure 13 Determination of initial and final position of knee angle with smartphone application [28]

Then the same measurements made with UG. In respect to study [28], following Table 3 shows the knee flexion angles of the three examiners on two different days using the smartphone application and the universal goniometer.

D1= first day; D2=second day; E1, E2, E3= examiners; M=mean; SD=standard deviation; R^2= coefficient of determination; ICC= intraclass correlation coefficient

	Smartphone		Goniometer		R^2	ICC (IC 95%)
	M	SD	M	SD		
D1E1	44,6	11,1	42,9	9,0	0,885	0920 (0,846–0,959)
D2E1	42,1	11,1	41,2	10,6	0,955	0976 (0,953–0,988)
D1E2	45,3	10,1	42,3	9,2	0,884	0935 (0,874–0,967)
D2E2	43,3	11,3	40,7	9,2	0,861	0909 (0,825–0,953)
D1E3	45,2	10,6	44,6	10,2	0,901	0949 (0,900–0,974)
D2E3	44,2	11,6	42,8	10,3	0,882	0933 (0,870–0,966)
Mean	44,1	10,9	42,4	9,7	0895	0,937 (0,878–0,968)

Table 3 Degrees of knee flexion of three examiners on different days using UG and smartphone app [28]

In respect to study [28], the measurements showed that a high degree of correlation was found between the two measurement methods. Considering the experimental procedures applied in the present study, angular measurements of knee flexion obtained using a UG were highly correlated with those obtained using the ROM goniometric app for a smartphone. According to these results, it was concluded that the accelerometer-based goniometric apps are useful tool for measuring ROM of different part of body in physiotherapeutic evaluations.

In agreement with the literature survey, it was concluded that accelerometer-based technology is the best and more accurate one comparing to other goniometric measurement methods. Also it was decided that, this method has been gaining ground in the health field due to its usability, reliability, validity and lack of technical difficulties. For these reasons, in this project, the accelerometer-based technology was used to obtain measurements from smartphone part, to provide precise reading of the ROM of knee.

4 Original Goniometer App development

The main objective of the project is to design an Android app which user will be able to measure the ROM of knee with the help of smartphone and wearable IoT device. The target area of the app is for patients who had knee injury or knee replacement surgery. The app will provide to patients, train recovery surgery exercises at home instead of going to hospital or rehabilitation places. Concerning to the literature survey, goniometric smartphone apps, as it is explained in section 3.2, are based on built-in smartphone's sensors and do not support reference point measurements which is essential to avoid compensation movements with other body parts.

The aim of the project is to measure the ROM of user's knee with the help of wearable IoT sensor referenced to the position of smartphone itself. In the further it would be possible to add additional wearable sensors for more precise monitoring of body movements targeting the compensation avoidance.

4.1 System Setup

In this project, mobile phone, wearable IoT sensor and sensors such as accelerometer and gyroscope are used. Two different angle data is calculated with respect to the ground by smartphone and IoT wearable device, and then the angle between smartphone and wearable sensor is calculated. Section 4.2 explains the measurement and calculation of the desired angle for the application. Following Figure 14 represents the use case scenario of the designed application and Figure 15 represents block diagram of the system.

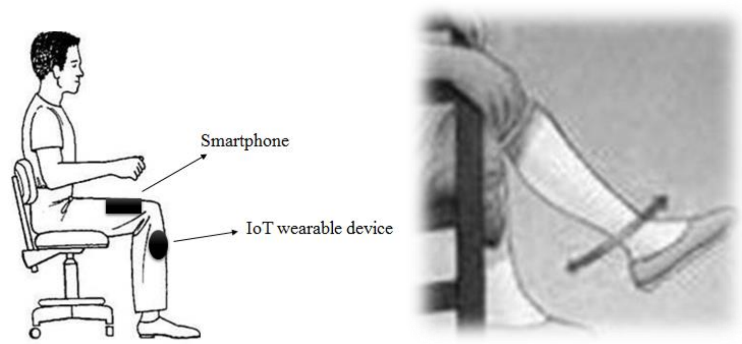


Figure 14 Use case scenario of the application

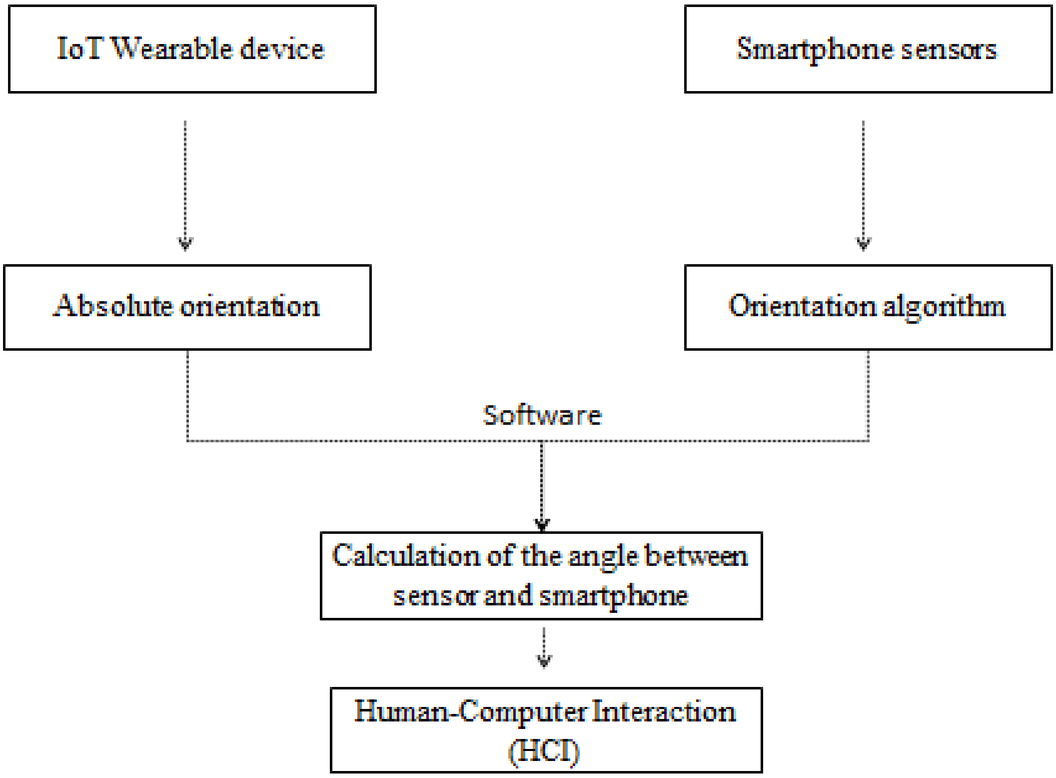


Figure 15 Block diagram of the system

Mobile Phone

Mobile phones have different built-in sensors and features. However, in most cases smartphones include at least accelerometer, gyroscope, proximity sensor, camera sensor etc. For this development, HTC Desire 516 Dual Sim with Android version 4.3 and Android JDK 1.8 was used.

The phone must have following features for this particular application to be developed;

- Android version 4.x or 5.x;
- Accelerometer sensor.

Wearable IoT device

The IoT wearable sensor is shown in Figure 16. The device and its firmware was developed earlier for Norwegian Green-ICT program for home monitoring of neurodegenerative disease patients. If the device is turned ON, the green LED is blinking at 1 Hz. If a user holds on the power button at least for one second, the red LED will flash and the device turns off. User can monitor the battery voltage level of the sensor device on smartphone application. The communication between sensor and the smartphone is over Bluetooth LE. This particular sensor has absolute position calculation software built in and outputs the device position referenced to the ground. 16-bit accelerometer, gyroscope and magnetometer data is used for that and processed by a Mahony filter algorithm.

.

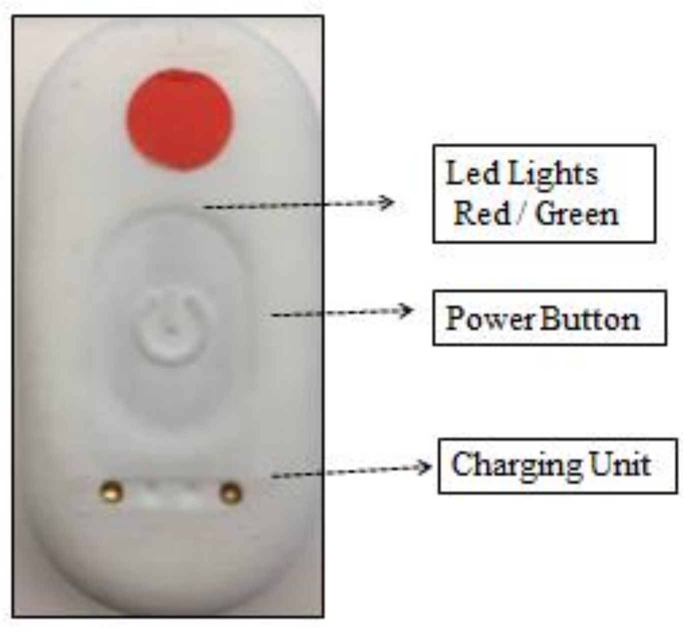


Figure 16 Bluetooth Sensor used in the project

4.2 Measurement of Angles

In this section, it is explained how to measure the desired angle between the smartphone and wearable device for the given use case scenario of the project. It is assumed that smartphone is kept in (relatively) static position and accelerometer readings caused by the gravity force are used for device orientation detection. The calculation of the static angle from accelerometer data will be explained in section 4.2.1.

On the other hand, gyroscope is used to calculate the angular movement. Integrating the gyroscope signal during the rotational movement gives more accurate displacement information. As mentioned wearable IoT device used in this project has an Inertial Measurement Units (IMU) device that internally calculates device orientation referenced to ground and uses for this purpose both accelerometer and gyroscope. Accumulation of integration errors is compensated with the use magnetometer also built into the IMU device. The calculation of the angle by wearable IoT device has been explained in section 4.2.2.

The algorithm of the application is designed to use two independent device orientations referenced to the ground, respectively from the wearable IoT device and smartphone. Later on, the angle measured by wearable IoT device was subtracted from the ground angle measured by smartphone. Figure 18 represents the overview of this process.

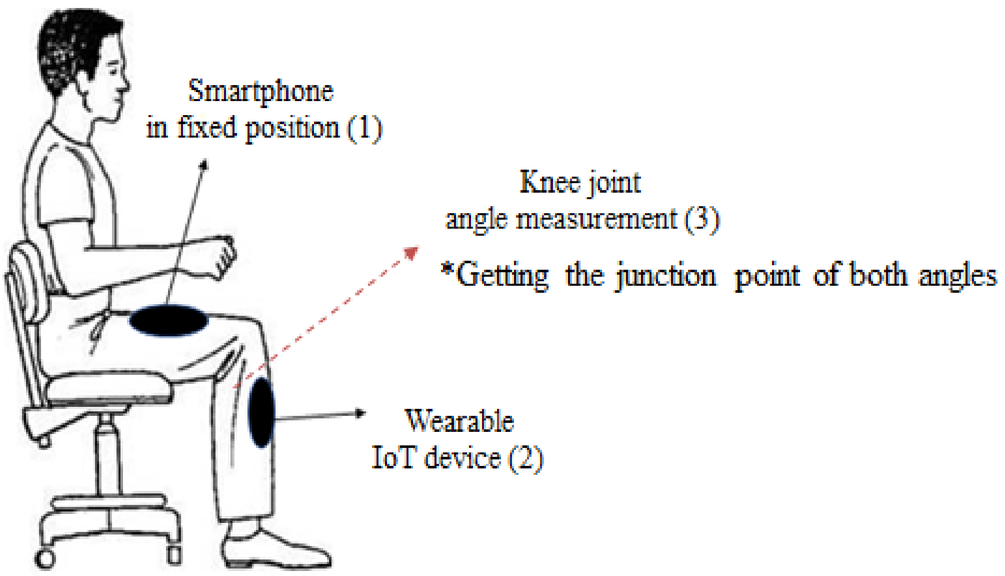


Figure 17 Example overview of the use case scenario

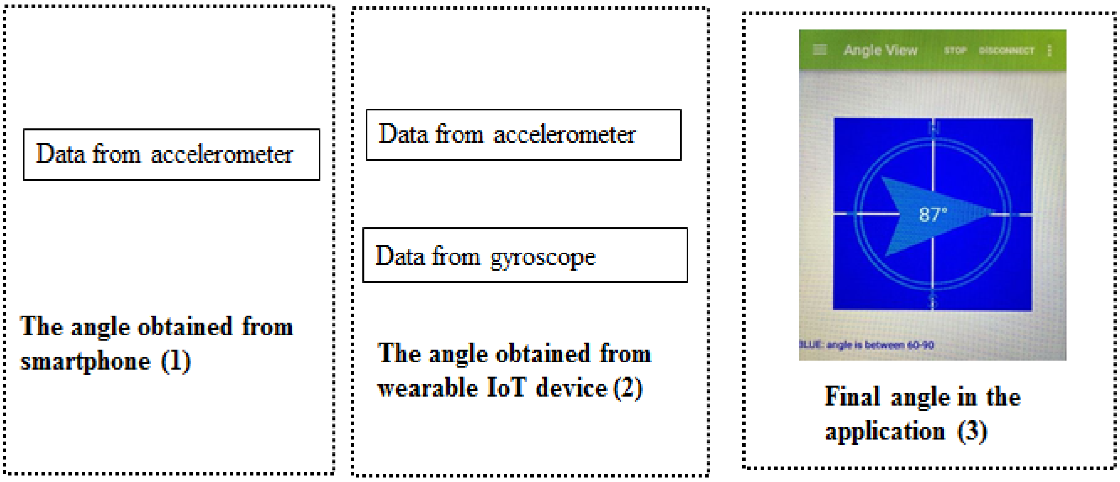


Figure 18 Calculation of the knee joint angle process

4.2.1 Getting angle data from smartphone by acceleration sensor

When the system is in a static condition, it is only required an accelerometer, preferably one with low noise and high resolution, to get accurate tilt angle. In dynamic system, this requires tracking rotation with gyroscopes or compasses [29].

As it was mentioned before, in the algorithm, the accelerometer sensor of smartphone was used to get first angle data with respect to the ground. While getting and calculating the desired angle in the system, the smartphone was placed in standing condition as it can be seen in above Figure 17. When the system is in a static condition, the desired angle from accelerometer sensors can be measured with different ways. These sensing methods are:

- Single-Axis;
- Dual-Axis;
- Triple-Axis.

In the algorithm, triple-axis sensing method was used to measure the angle of smartphone. The comparison of these methods and formulas of standing conditions have been explained in the following part.

Measuring tilt using single axis

A single-axis device can be used in applications where the inclination sensing is needed only over a limited angle. Basically in this method, the tilt algorithm is limited to one axis of sensitivity; it uses only a single axis and gravity vector. As shown in Figure 19, the accelerometer is rotated through gravity and tilted along the x-axis [30]

The calculated angle of inclination can be accurate only when the accelerometer is moved in the x-axis. Any rotation of other axes will reduce the magnitude of the acceleration on the x-axis, which will result in error in the calculated angle of inclination.

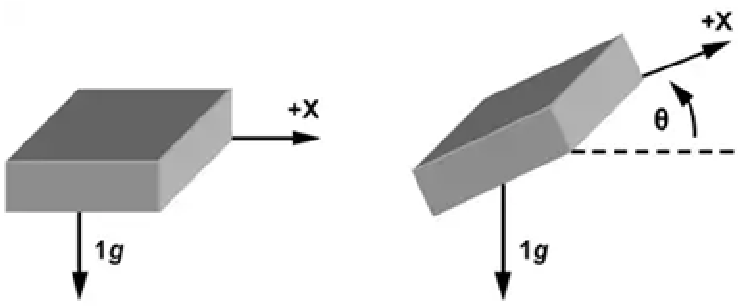


Figure 19 Single axis used for tilt measuring

In particular to knowledge in trigonometry, the projection of the gravity vector on the x-axis will produce output acceleration which is equal to the sine of the angle between the horizon and the x-axis of accelerometer.

The equation of the output acceleration, for an ideal value of 1 g for gravity is:

$$A_{x,out}[g] = 1g \times \sin(\Theta) \quad (1)$$

Therefore, the angle becomes the following:

$$\Theta = \sin^{-1}(A_x) \quad (2)$$

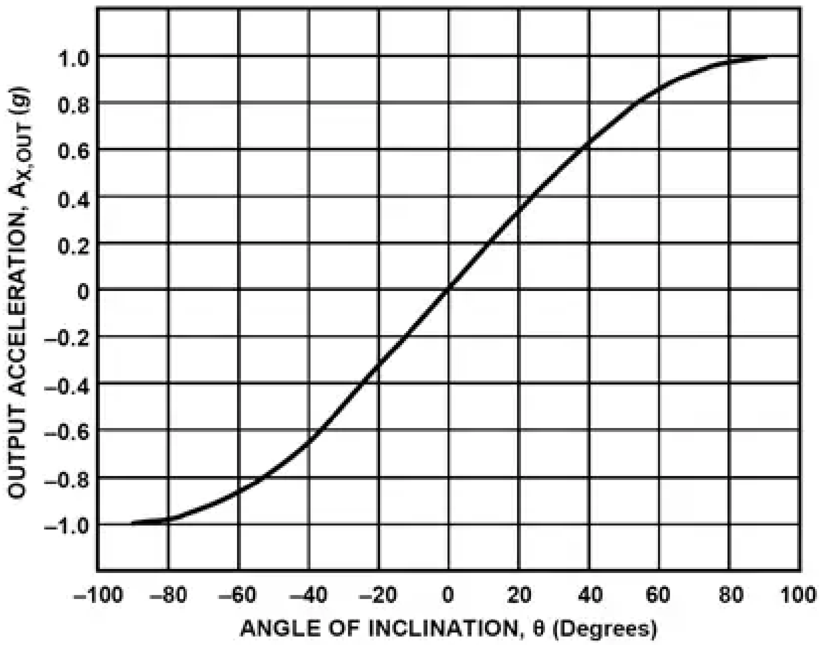


Figure 20 Accelerometer’s output when tilted from -90° to 90°[30]

In Figure 20, the graph represents the relation between the outputs of the accelerometer as it tilts from -90° to +90°. It can be concluded that, the sensitivity decreases as the angle between the x-axis and the horizon increases. Also in this method, the disadvantage is that, it is not possible to know the difference between two tilt angles that result in the same sensor output.

Measuring tilt using dual axis

Mainly, there are three major advantages to including a second axis in measuring the tilt angle. First of these advantages, is orthogonality of the axes. As it can be seen in below Figure 21, the Y axis acceleration is related to the cosine of the angle of inclination [30]. The sensitivity of the one axis increases, as the sensitivity of second axis decreases.

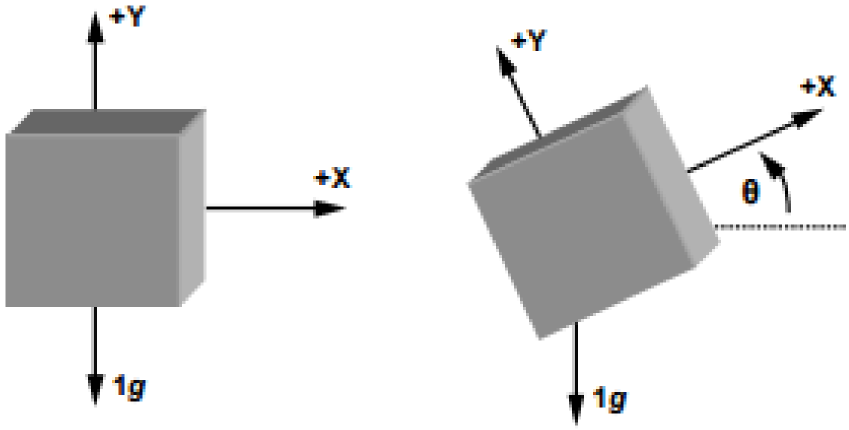


Figure 21 Two axes used for tilt sensing

The second benefit is that including a second axis in determining the angle of inclination, produces a more accurate solution. Lastly, this sensing method provides the ability to distinguish between each quadrant and to measure the angle all through an entire 360° arc [30].

As it can be seen from the below graph that the component due to gravity on the Y-axis follows the cosine function while the component due to gravity acting on the X-axis follows the sine function.

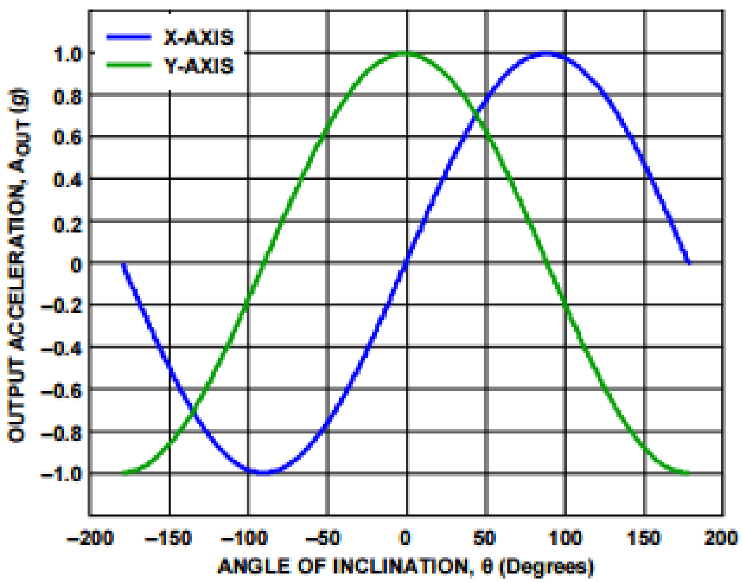


Figure 22 Relation between output acceleration and angle of inclination

According to the graph in Figure 22, it can be concluded that in the Y direction, the sensitivity is at its minimum while the X sensitivity is at its maximum and vice versa. Thus, by combining the X and Y outputs, the maximum tilt sensitivity can be maintained. In particular to knowledge in trigonometry, the Y axis is calculated in a similar fashion as the calculation of the X axis before, by remembering to use the cosine of the angle.

$$A_{x,out}[g] = 1g \times \sin(\Theta) \quad (3)$$

$$A_{y,out}[g] = 1g \times \cos(\Theta) \quad (4)$$

By using the ratio of the values of the above equations, it can be found the inclination angle, Θ, as in the following equation:

$$\frac{A_{x,out}[g] = 1g \times \sin(\Theta)}{A_{y,out}[g] = 1g \times \cos(\Theta)} = \tan(\Theta) \quad (5)$$

$$\theta = \tan^{-1}\left(\frac{A_{X,OUT}}{A_{Y,OUT}}\right) \quad (6)$$

Measuring tilt using triple axis

In tri-axial accelerometers, X, Y, and Z axes can sense tilt. As the Z axis can be combined with both of the tilting axes, this method will improve the tilt sense precision and accuracy [31]. According to the below Figure 23, it can be concluded that X and Y axis follow the sine function while the Z axis follows the cosine function.

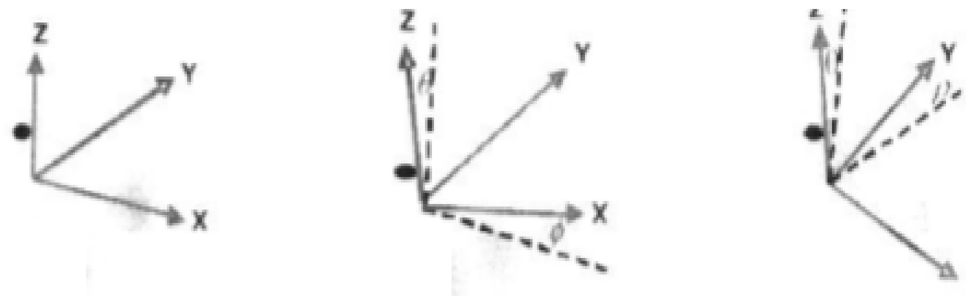


Figure 23 X, Y and Z axes tilt relative to ground

The orientation of the sensor can be settled in a complete sphere by introducing a third axis. In three dimensions, to define the angles of the accelerometer, the pitch, roll and theta are sensed using all three outputs of the acceleration. Roll (φ) is defined as the angle of the Y-axis relative to ground. Pitch (ρ) is described as the angle of X-axis relative to ground and finally theta (Θ) is the angle of the Z-axis relative to gravity (31).

According to these descriptions, following Figure 24 shows the angles of spherical coordinate system. This method is used to measure the angle of the smartphone in the project because basically three angle sensing is needed for human movement.

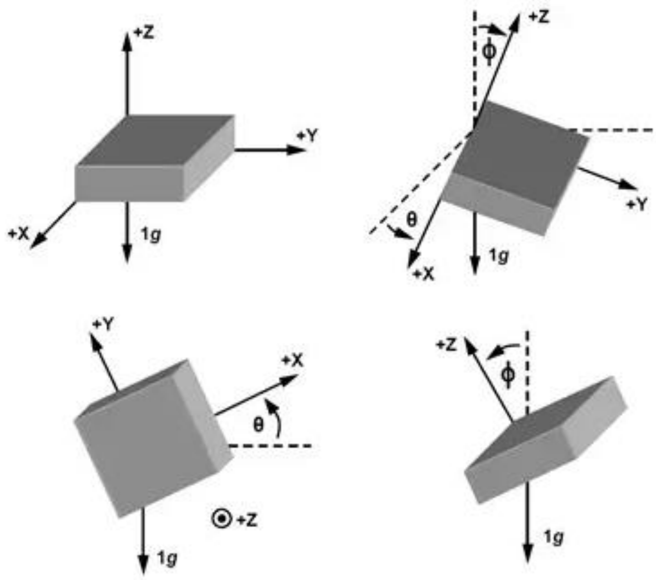


Figure 24 The angles of spherical coordinate system

The classical method of rectangular (x, y, z) to spherical (p, θ, φ) conversion can be used to relate the angle of tilt in the xy-plane, φ, and the angle of inclination from the gravity vector, φ, to the measured acceleration in each axis. Thus:

$$\phi = \cos^{-1}\left(\frac{A_{Z,OUT}}{\sqrt{A_{X,OUT}^2 + A_{Y,OUT}^2 + A_{Z,OUT}^2}}\right) \quad (7)$$

$$\theta = \tan^{-1}\left(\frac{A_{X,OUT}}{A_{Y,OUT}}\right) \quad (8)$$

4.2.2 Getting angle data from IoT wearable device by acceleration and gyroscope sensors

Sensor Fusion is a process that Inertial Measurement Unit data from several different sensors such as Accelerometer, Gyroscope and Magnetometer are fused to compute something more than could be settled by any one sensor alone. This process improves reliability, accuracy and filtering IMU sensors data [32]. In this case, this process is used in wearable device sensor to get the data from three angle sensing, as the movement just in one axis is not possible for human.

An accelerometer is very sensitive sensor to vibration and mechanical noise even it is relatively stable. On the other hand, even gyroscopes are less sensitive to linear mechanical movements; they have drift problem. So by sensor fusion process these problems can be achieved, and averaging the data that comes from accelerometer and gyroscopes can produce a better estimate of the orientation [32]. With the help of sensor fusion, each sensor will be able to compensate for the bias induced by others in the mechanism of wearable device. The mechanism of getting data and calculating the angle from IoT wearable device can be seen in below Figure 25.

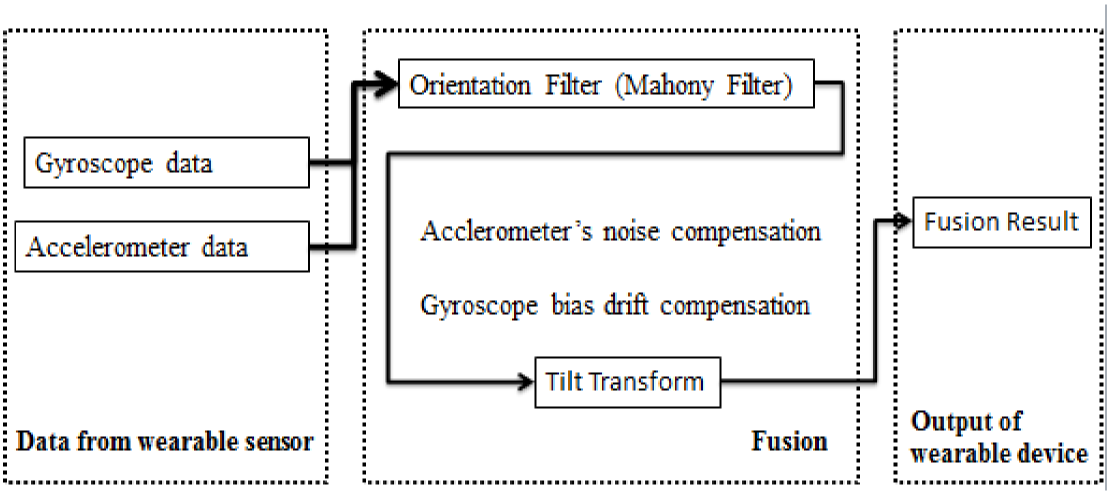


Figure 25 The mechanism of measuring the angle by IoT wearable device used in project

The angular velocity from gyroscope will be merged with the Earth gravitational which is measured by accelerometer to compute complete and single estimate of the orientation angle. As it was mentioned previously, the IoT wearable device has absolute position calculation software built in and outputs the device angle respect to the ground. 16bit accelerometer, gyroscope and magnetometer data is used for that and processed by a Mahony filter algorithm, particular algorithm used for compensation of sensor nonlinearities and drifts is kept confidential be the IMU manufacturer. Absolute position is expressed in quaternions that are converted to position referenced to ground in smartphone.

A quaternion is basically four component vector which is used to encode any rotation in a 3D coordinate system [33]. A 3D body, in this case the IoT wearable device, can be rotated about three orthogonal axes, as it can be seen in below Figure 26. These rotations are referred to as yaw, pitch, and roll.

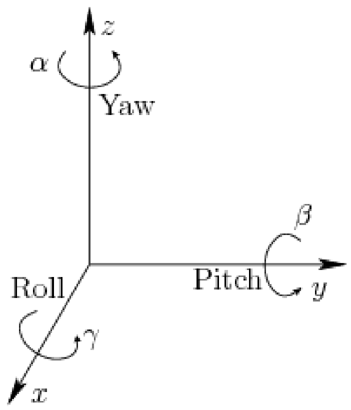


Figure 26 Three dimensional rotation

- Yaw: This is the angle between the sensor's current compass direction and magnetic north. It is a counter clockwise rotation of α about the z axis. In the matrix, z coordinate remains constant and 2D rotation is applied to the x and y coordinates. Thus the rotation matrix is given by;

$$R_z(\alpha) = \begin{pmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix}. \tag{9}$$

- Pitch: This is the angle between a plane parallel to the sensor's screen and a plane parallel to the ground. It is a counter clockwise rotation of ß about the y axis. The rotation matrix is given by;

$$R_y(\beta) = \begin{pmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{pmatrix}. \tag{10}$$

- Roll: This is the angle between a plane perpendicular to the sensor's screen and a plane perpendicular to the ground. It is a counter clockwise rotation of γ about the x axis. The rotation matrix is given by;

$$R_x(\gamma) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{pmatrix}. \tag{11}$$

As it was mentioned previously, the yaw, pitch and roll rotations can be used to place 3D body, in this case the wearable IoT sensor, in any orientation. The obtained matrix by multiplying the yaw, pitch, and roll rotation is given by;

$$R(\alpha,\beta,\gamma) = R_z(\alpha)\,R_y(\beta)\,R_x(\gamma) = \begin{pmatrix} \cos\alpha\cos\beta & \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma & \cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma \\ \sin\alpha\cos\beta & \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & \sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma \\ -\sin\beta & \cos\beta\sin\gamma & \cos\beta\cos\gamma \end{pmatrix} \quad (12)$$

Algorithm implementations of getting and calculating the angle from the smartphone and IoT wearable sensor have been shown and explained in section 4.4.

4.3 Communication between the Smartphone and IoT Sensor

In the project, Generic Attribute Profile (GATT) is used to provide the communication between smartphone and IoT wearable sensor. GATT establishes the framework and all other common operations to transport the data. It is implemented and updated on top of the Attribute protocol (ATT). Basically, ATT stores the GATT (34)

The GATT layer of the BLE Protocol Stack is basically designed to be used by the app for data communication between two connected devices. GATT protocol is based on simple server-client relationship.

- GATT Client: It is responsible to send a request to the GATT server. The client is the device that is reading/writing data from /to the GATT server.
- GATT Server: Main role of the server is to store attributes. The server is the device containing the data that is being read/written by the GATT client.

The following Figure 27 represents the diagram that illustrates the data exchange process between a peripheral which is the GATT server and a central device which is the GATT client.

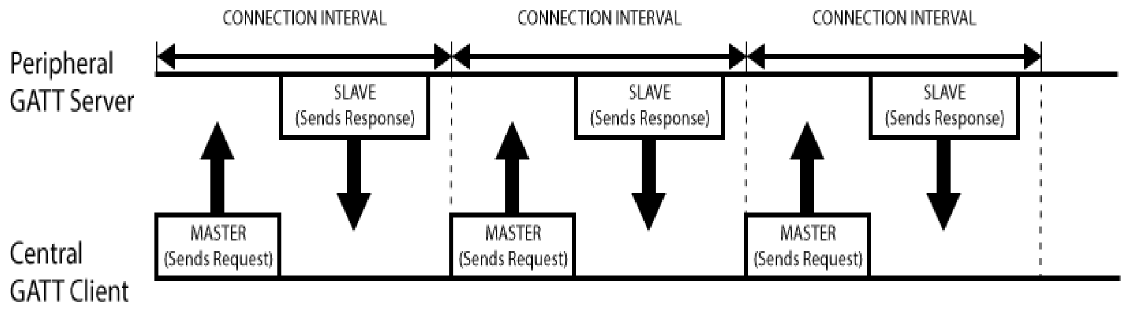


Figure 27 Data exchange process

The peripheral which is GATT server, holds the ATT lookup data and service and characteristic definitions, and the GATT client which is responsible for sending requests to this server. As it can be seen in the Figure 27, all the transactions are started by the master device, the GATT Client, which receives response form the slave device, the GATT server [34]. In the project, the IoT wearable sensor is GATT server which offers the data for reading and writing, on the other hand smartphone is GATT client which reads the data from the GATT server. As it has been explained in section 4.4, by Service and Utils folders GATT protocol is provided to make communication between smartphone and IoT wearable sensor in the project.

Following Figure 28 represents the diagram that explains the way that Bluetooth Low Energy 4.x devices work in a connected environment. As it can concluded from the figure that, a peripheral can only be connected to one central device at a time, but meanwhile the central device can be connected to multiple peripherals [35]. Current IoT device does not support newer BLE 5.x communication standard that supports also more complex network architectures.

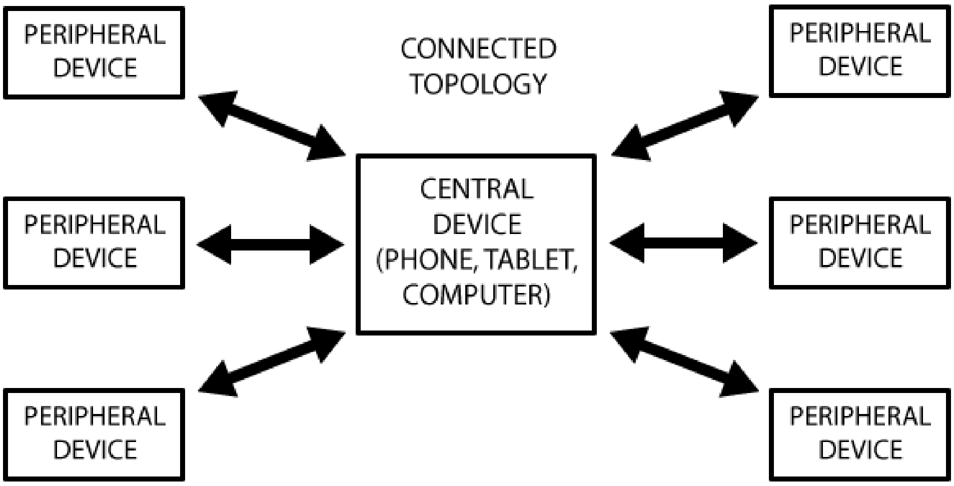


Figure 28 Bluetooth Low Energy Star Topology

GATT transactions in Bluetooth Low Energy are based on Profiles, Services and Characteristics [35].

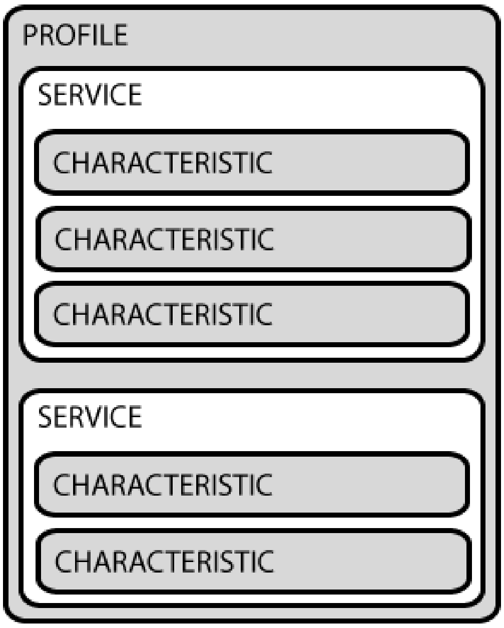


Figure 29 Simple diagram that shows how GATT transactions in BLE are based on

- A Profile is simple pre-defined collection of Services, as shown in Figure 28;

- Characteristics contain a value, characteristic properties, and a characteristic declaration. They are the lowest concept in GATT transaction as it can be seen in Figure 29. Characteristic is used as a value in a service. This value is used with information that shows how to represent and/or display a value, how to access this value and also information about its configurations;

- Service is a data collection and all the related behaviours to either accomplish a device portion or a device feature or to create a certain function. It can either contain a set of characteristics that will structure it or can reference other services, as it was described in above Figure 29.

4.4 Structure of the Application

This section contains information about the structure of original goniometer application. General project structure can be seen in following Figure 30.

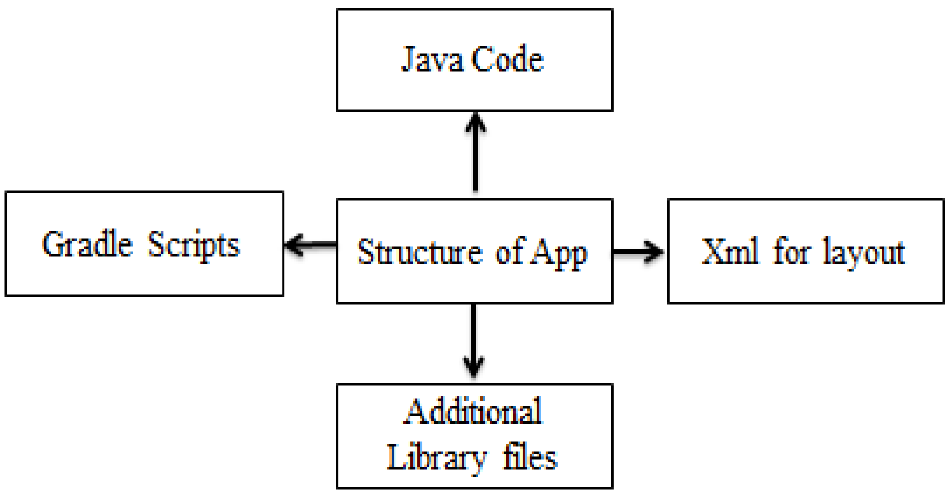


Figure 30 The modules of the project structure

4.4.1 Gradle Scripts

Gradle scripts are used to build Android studio projects. Language is based on scripting language Groovy [36]. Each file has its own scope and can contain local variables, build data, arbitrary objects etc. [37].

In the project structure, there are three build.gradle files. These are;

1. BLEWearableDeviceOriginal: This file contains the build script of the project.
2. App (build.gradle): This file is gradle file of the project. Contains sdk version for compile, build tool version for android studio, java version info, application id, minimum sdk version for running the application, target sdk for compiling, version code, version name and application dependencies for running.
3. Settings.gradle: This file contains project including file types.

4.4.2 Java Files

Android projects are written in object oriented Java programming language that was developed by James Gosling in 1996 for Sun Microsystems, and currently maintained by Oracle [38]. It has high range of compatibility from embedded devices to high level systems. Java codes are compiled into JavaByteCode which run into JVM (Java Virtual Machine). With that, java codes can run into systems which have suitable JVM installation. This programming language can run on Unix systems, Windows systems and MacOs systems.

The designed original goniometer app is developed by Android studio and the java files are arranged in 8 folders. The project tree of these files can be seen in Figure 31 and each folder is explained respectively in the following part.

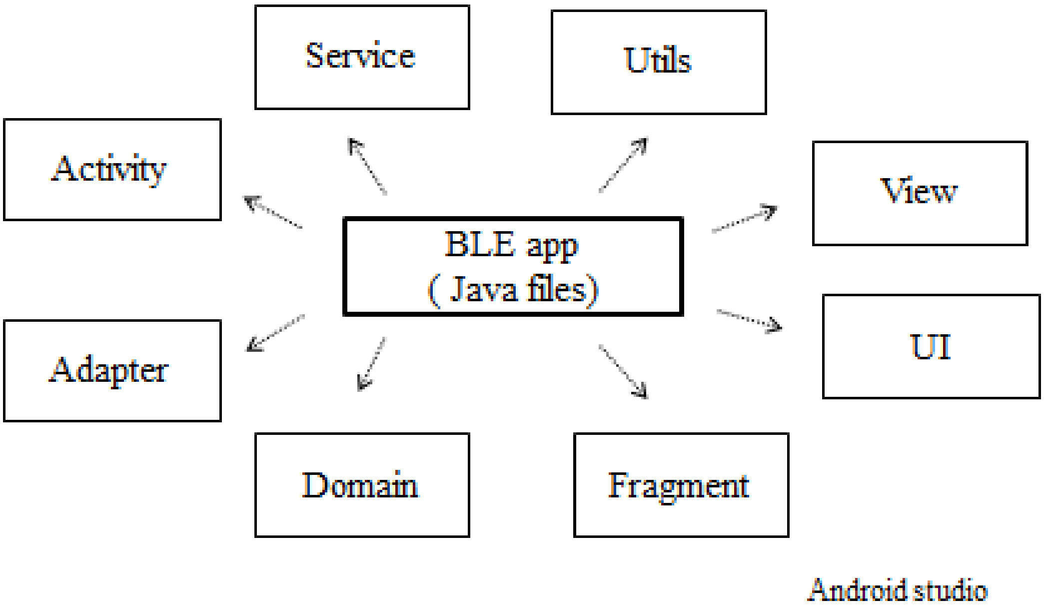


Figure 31 Project tree of java files

Activity folder

The structure of this folder is designed with two files

1. BleDeviceScanActivity: This file is used for device scanning activity and it's user interface (ui) file is ble_device_scan_activity.xml. Simply it manages the mentioned ui file and makes transaction between ui states.

2. BleMainActivity: This file is used for main activity for adding a device to application. Ui file of it is ble_main_activity.xml. Basically the file is also responsible for following tasks:

- Declaring 'OnDeviceStatusListener ' interface for changing device status. This interface has different functions for device status listening. Any other file that implements this interface, can listen devices connection status, recording status, battery status and incoming data status.
- Making a new service connection to IoT device.
- By 'onCreate' function, checking if Bluetooth Low Energy is supported

- Binding the BLE connection to service
- Managing and doing tasks from Options Menu from UI.
- Handling the connection, disconnection, recording and toggle led functionality.
- With ‘Incoming MessagesHandler ' class, handles the incoming messages. This class also extends SDKs Handler class and adds some functionality for the application.

Adapter folder

The structure of this folder is designed with two files.

1. BleDeviceListAdapter: Used for showing devices that is found after Bluetooth scan and its ui file is: ble_device_listitem.xml. It organizes the list for found devices and manages ui file.

2. DeviceListAdapter: This file is used for devices that are added to application. It also includes devices that found after scan process and devices which were added previously. Its ui file is device_listitem.xml. Other responsible tasks of this file are:

- Managing the UI.
- Creating 'ViewHolder' class which keeps the device’ specific information.
- Representing the added device’s name, connection status and battery status.

Domain folder

This folder is used for general proprieties of IoT wearable sensor. It is extended from Sugar Record which is an open source Android Database. This class is used for managing devices database. Detailed information can be found in [39].

Fragment folder

The structure of fragment folder is designed with five files.

1. AngleFragment: The calculation of the angle between smartphone and IoT device is provided in this file. Also it is used for managing and updating angle_fragment.xml ui file. The file is also responsible for following tasks:

- Implementing 'BLeMainActivity.OnDeviceStatusListener' interface for device status, incoming data etc. functionality
- Extending Fragment class for UI tasks.
- Calculation of smartphones angle via accelerometer with 'SensorEventListener'.
- Calculates the angle between smartphone and sensor with 'onDataChanged' function and it sends angle data to 'AngleMeter'.
- Managing the 'AngleMeter' class. 'AngleMeter' is an open source project and it is used for representing the angle value in understandable way [40].

2. BleConfigurationFragment: The configuration of device proprieties is provided by this file. The ui file of it is ble_configuration_fragment.xml. This file is responsible to arrange features of device such as gyroscope range, accelerometer range, sensor sampling rate and 100g sensor range. It also creates and updates records for configuration.

3. BleDeviceScanFragment: Used for Bluetooth device scanning and its ui file is ble_device_scan_activity.xml. Basically it saves founded devices to devices list, manages the UI, starts and stops the scanning process and requests permission for enabling the Bluetooth at smartphone.

4. BleDevicesFragment: This file is used to manage and update ble_devices_fragment.xml ui file. The file is also responsible for following tasks:

- Showing status if device is in a list
- Showing device's specific features

- Implementing ‘BLeMainActivity.OnDeviceStatusListener’ interface
- Implementing ‘View.OnClickListener’ interface
- Extending the ‘SwipeRefreshListFragment’ class for enabling the ability to trigger a refresh from swiping down on the view.

5. SwipeRefreshListFragment: Refreshing the Bluetooth devices list is provided by this file. This file also provides the extending ‘ListFragment’ class for fragment that displays a list of items by binding to a data source such as an array or Cursor, and exposes event handlers when the user selects an item [41].

As it was mentioned, the calculation of the angle with smartphone’s accelerometer has been done in ‘Angle Fragment’ file. For this process;

1. Android ‘device status listener’ was implemented with following code to be able to access the sensors of the smartphone;

```
public class AngleFragment extends Fragment implements
BleMainActivity. OnDeviceStatusListener
```

2. Sensor manager object was created and configured to receive information from the accelerometer with following code;

```
public void onAttach(Activity activity) {
super.onAttach(activity);
mSensorManager = (SensorManager)
activity.getSystemService(Context.SENSOR_SERVICE);
mSensor = mSensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER);
mSensorManager.registerListener(Listener, mSensor,
SensorManager.SENSOR_DELAY_NORMAL);
if(activity instanceof BLeMainActivity){
Log.d(TAG, "Attach listener");
((BLeMainActivity) activity).setOnDeviceStatusListener(this);
}}
```

3. Accelerometer listener implemented. By this way, with following code it was possible to get data from the accelerometer sensor of the smartphone which can be constantly updated;

```
public SensorEventListener Listener = new SensorEventListener() {
public void onAccuracyChanged(Sensor sensor, int acc) { }

public void onSensorChanged(SensorEvent event) {
       x = event.values[0];
       y = event.values[1];
       z = event.values[2];
      Log.d(TAG, "Accelometer:" + " data: " + "x=" + String.valueOf(x) + "---" + "y="
+ String.valueOf(y) + "---" + "z=" + String.valueOf(z));
      angle = (float) (Math.atan2(x, y)/(Math.PI/180));
      dataView.changeData1("Device angle=  " + String.valueOf(angle) );

      //textX.setText("X : " + (int)x + " rad/s");
      //textY.setText("Y : " + (int)y + " rad/s");
      //textZ.setText("Z : " + (int)z + " rad/s");
   }};
```

On the other hand, also the calculation of the angle between smartphone and IoT wearable device has been done in 'Angle Fragment' file. For this process; onDataChanged method was called, whenever is needed to get new data from the system. In this method, it was performed the subtraction operation with angle of the smartphone and IoT wearable sensor. With 'AngleMeter'class, the obtained angle have been shown in the application interface. The following code represents this process;

```
public void onDataChanged(String address, String data) {
   Log.d(TAG, "data from:" + address + " data:" + data);

   dataView.changeData(address, data);
   //dataView.changeData1("data: " + "x=" + String.valueOf(x) + "---" + "y=" +
String.valueOf(y) + "---" + "z=" + String.valueOf(z));
   //Log.d(TAG, "Received:" + "data: " + "x=" + String.valueOf(x) + "---" + "y=" +
String.valueOf(y) + "---" + "z=" + String.valueOf(z));
   angleView.changeData(address, data);

String[] tokens = data.split("\\|");
float angleSensor = Float.valueOf(tokens[0]);
float angle = Integer.valueOf((int) angle)-(int)angleSensor);
angleMeter.setAngle(Integer.valueOf((int) angle)-(int)angleSensor);
```

Service folder

The structure of this folder is designed with two files.

1. BleDeviceHandler: This class is used for device handler. This file is also responsible for following tasks:

- Managing the device proprieties
- Organizing services for the device
- Arranging Bluetooth GATT service [34] event such as connection, connection status, enabling data services from different sensors on device
- Setting configuration of device
- Implementing 'DisableCharacteristicNotificationCommand' thread class extends from Runnable (Thread base class) for disabling notifications from device.
- Implementing 'ReadDescriptorCommand' thread class extends from Runnable (Thread base class) for reading device specific descriptor
- Implementing 'WriteDescriptorCommand' thread class extends from Runnable (Thread base class) for writing device specific descriptor.
- Implementing 'WriteCharacteristicCommand' thread class extends from Runnable (Thread base class) for writing command to device.
- Implementing 'ReadCharacteristicCommand' thread class extends from Runnable (Thread base class) for reading command from device.
- Calculating and updating the battery value;
- Getting and calculating the angle of the IoT wearable device;
- Updating and calculating the angle data with 'updateDataBytes' function.
- Updating the 100g sensor data.

2. BleDeviceService: This file is mainly used for device's service operations. It is also responsible for following tasks:

- Keeping device handling variables
- Incoming message handling
- Implementing 'CheckDeviceHandlersTask' thread class extends from Runnable (Thread base class) for checking device status, connecting and disconnecting events.

In this section, the calculation of the wearable IoT sensor was provided by conversion process of the quaternions to Roll, Pitch, and Yaw rotations. These parts of the algorithm were already implemented to the system earlier, so it was not developed by me.

Utils folder

The structure of this folder is designed with two files.

1. BleWearableSensor: This part is used for keeping characteristics strings for our device's services and sensors. This data is provided by universal GATT descriptors [42].

2. BluetoothGattAttributes: This is used for keeping generic characteristics strings for GATT services and sensors.

View folder

The structure of this folder is designed with two files.

1. AngleView: This file is used for drawing the angle in testing state.

2. DataView: The file is used for writing the data that come from device in testing state.

UI folder

UI file stores the user interface configuration for a program; saved in an .xml format. Also it contains definitions of Qt widgets with slots and signals which can be viewed in a basic text editor or can be opened with a UI designer program [43]. Basically, this folder is keeping the ui xml files. It is used to keep all the ui's, icons for the app, app logo, and data value list for combo boxes and text appearance settings.

5 Information about the Goniometer App

This section contains overall information about the developed original goniometer app 'BLE', which some parts of the algorithm were already implemented earlier. Following Figure 32 represents the home screen of the developed app. Main menu contains 'Devices', 'Configuration' and 'Angle View' parts.

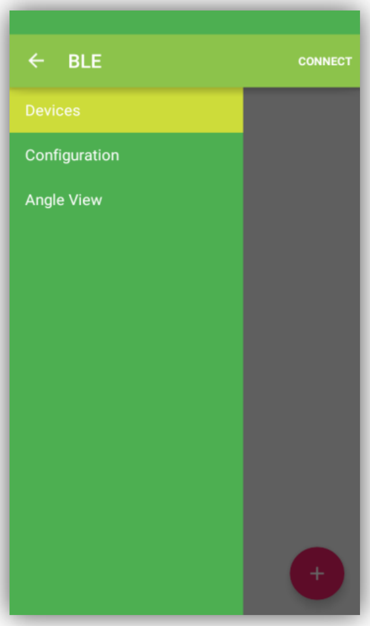


Figure 32 Main menu page

From the section '+', any IoT wearable sensor can be found via Bluetooth and then can be connected to the developed app. In the project, name of the IoT wearable device is 'Eliko hack!' and it is connected to the app as it can be seen in Figure 33.

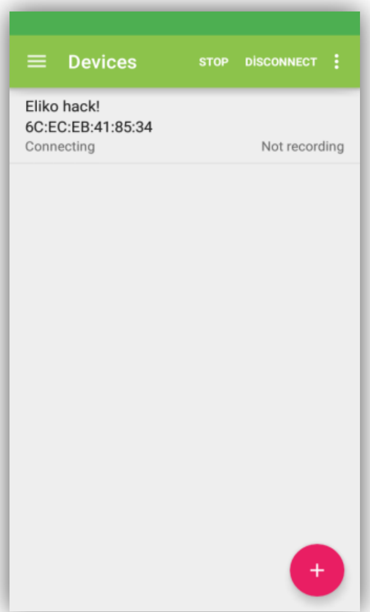


Figure 33 Scan page

The user can see which devices are connected to the app, and then configure ‘Range of accelerometer’, ‘Range of gyroscope’ and ‘Sample rate’ dropdown options. Figure 34 represents the overall configurations page.

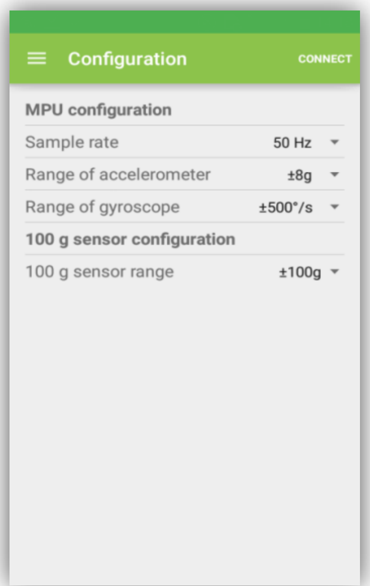


Figure 34 Configurations page

Sample Rate: This dropdown option contains the value of ‘50 Hz’ and ‘100 Hz’. 50 Hz is selected as a default.

Range of Accelerometer: This dropdown contains the value of ‘2g’, ‘4g’, ‘8g’ and ‘16g’ values. 8g is selected as a default.

Range of Gyroscope: This dropdown option contains ‘250°/S’, ‘500°/S’, ‘1000°/S’ and ‘2000°/S’ values. ‘500°/S’ is selected as a default.

100g Sensor Range: This dropdown option contains ‘100g’, ‘200g’ and ‘400g’ values. ‘100g’ is selected as a default.

The ‘Angle View’ section represents the goniometric measurement results of the app. The representation of the angle is shown with the 360° script. Basically, if the angle between smartphone and connected wearable IoT device is lower than 60°, the background colour of script turns green. If the angle is between 60° and 90°, the colour turns to blue and if it is higher than 90°, the colour turns to red. The representation of different results can be seen in Figure 35.

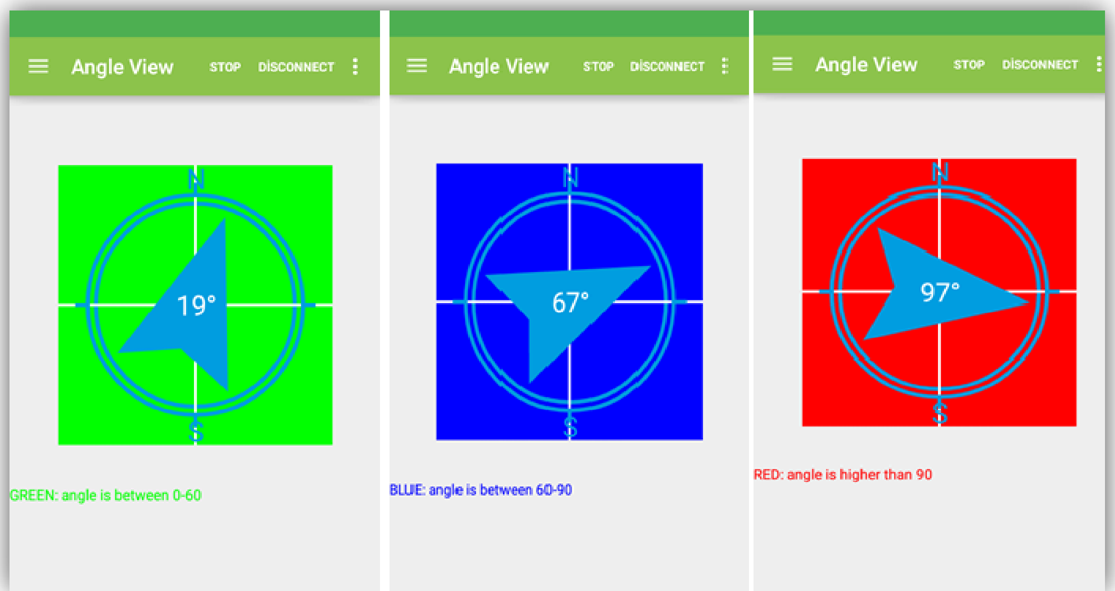


Figure 35 Angle View page

6. Experimental Results

This section contains experimental results of the system. The Table 4 below represents the descriptive analysis and summary of data measured from the original goniometer 'BLE' smartphone application with the assessment of IoT wearable device. These measurements were made in seated position and the smartphone was placed into fixed position.

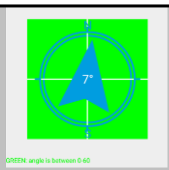
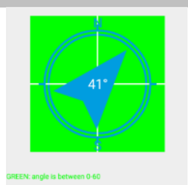
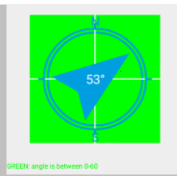
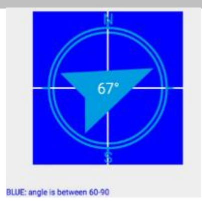
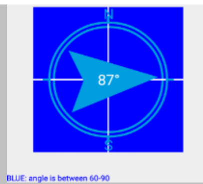
Pre-determined angle value	Obtained angle measurement	Representation of the angle in the software	Standard deviation
0°	7° 4° 8°		± 2.08°
30°	41° 27° 38°		± 7.37°
45°	53° 40° 49°		± 6.65°
60°	67° 65° 70°		± 2.51°
90°	87° 93° 85°		± 4.16°

Table 4 Obtained results from the smartphone application

7. Summary

The aim of the thesis was to focus on development of smartphone application based solution that can assist patients for home trainings, specifically patients who need perform exercises for knee joint. The main goal was to develop more sophisticated goniometer system that allows the angle measurement between the smartphone and wearable IoT device. System was implemented in respect to calculate patient's range of motion of the knee especially in seated position. Considering the experimental procedures employed in the present study, it has been concluded some limitations and possible errors of the algorithm. According to the obtained results from the smartphone application, the system showed an average standard deviation of ±4.55° in seated position. These are may be caused by accuracy of accelerometer sensor of the smartphone used for the development, accuracy of the IoT wearable sensor, android sensor manager library errors, conversion errors in the algorithm and zeroing factor. In future work, the accuracy and reliability of the application can be developed. Different Bluetooth sensors can be implemented in respect to obtain better measurement results. Also the technology shall be applicable for monitoring other limb and hip joints as well.

8. References

[1] Cap Gemini, ‘‘*Wearable Devices and their Applicability in the Life Insurance Industry*”, 2015

[2] *‘‘Nordum, Amy’’* [Online]. Available: http://spectrum.ieee.org/tech-talk/telecom/internet/popular-internet-of-things-forecast-of-50-billion-devices-by-2020-is-outdated [Accessed: 28 April 2017]

[3] *‘‘Wearables Market to be worth $25 Billion by 2019’’* [Online].Available: http://www.ccsinsight.com/press/company-news/2332-wearables-market-to-be-worth-25-billion-by-2019-reveals-ccs-insight [Accessed: 2 May 2017]

[4] H.H.Asada, A.Reisner, R.Sokwoo and R.C.Hutchinson, *‘‘Mobile monitoring with wearable photoplethysmographic biosensors*’’, Vol.22, 2003

[5] ‘‘*GyroGlove*’’ [Online]. Available: http://www.gyrogear.co [Accessed: 15 March 2017]

[6] Road, James Gichuru, *‘‘Earphones that track heart rate’’*, 2014

[7] David Andre, Astro Teller, *‘‘Future of Health Technology’’*, 2005

[8] *‘‘Hexoskin Wearable Body Metrics’’* [Online]. Available: http://www.hexoskin.com [Accessed: 2 April 2017]

[9] Damon Mccune, John C.Young, Mark Debeliso and James W.Navalta, *‘‘Using Hexoskin Wearable Technology to Obtain Body Metrics During Trail Hiking’’*

[10] ‘’Wireless Blood Pressure Monitor’’ [Online]. Available: https://www.withings.com/eu/en/products/blood-pressure-monitor [Accessed: 10 April 2017]

[11] *‘‘Xsens”* [Online] Available: https://www.xsens.com [Accessed: 25 April 2017]

[12] *‘‘MVN BIOMECH”* [Online] Available: https://www.xsens.com/products/mvn-biomech [Accessed: 25 April 2017]

[13] Jun Tian Zhang, Alison C. Novak, Brenda Brouwer and Qingguo Li, *‘‘Concurrent validation of Xsens MVN measurement of lower limb joint angular kinematics”*, 2013

[14] ‘‘*How a Physical Therapist Can Hlep with Exercise’’* [Online]. Available: http://www.spine-health.com/treatment/spine-specialists/how-a-physical-therapist-can-help-exercise [Accessed: 15 April 2017]

[15] Young MA, O’Yang B and Steins SA, *‘‘Knee Rehabilitation After Surgery’’*, 1997

[16] *‘‘Principles of Goniometry’’* [Online]. Available: http://highered.mheducation.com/sites/0071474013/student_view0/chapter8/goniometry.html [Accessed: 28 April 2017]

[17] Patrizia Milani, Carlo Alberto Coccetta, Giuseppe Massazza and Tommaso Sciarra, *‘‘Mobile Smartphone Apps for Body Position Measurement in Rehabilitation: A Review of Goniometric Tools’’*, Vol.6. 2014

[18] ‘‘*Important Information for the patients of Total Knee* Replacement’’ [Online] Available: http://www.drmavalankar.com/imp-total-knee-replacement.php [Accessed: 20 April 2017]

[19] Giorgio Ferriero, Stefano Vercelli, Francesco Sartorio and Susana Munoz Lasa. ‘‘*Reliability of a smartphone-based goniometer for knee goniometry*’’, Lippincott Williams & Wilkins, 2013

[20] Ockendon M, Gilbert RE. ‘‘*Validation of a novel smartphone and accelerometer based knee goniometer*’’*, 2012*

[21] Shin SH, Rodu H, Lee OS, Kim Sh, ‘‘*Within day reliability of shoulder range of motion measurement with a smartphone*’’, Man Ther, 2012

[22] JY and Jenny, ‘‘*Measurement of the knee flexion angle with a smartphone app is precise and accurate*’’, J Arthroplasty, 2013.

[23] Jones A, Sealey R, Crowe M and Gordon, ‘‘*Concurrent validity and reliability of the SimpleGoniometer iPhone app compared with the UG*’’, Physiother Theory Pract.

[24] Mitchell K, Guiterrez SB, Sutton S and Morton S, ‘‘*Reliability and validity of goniometric iPhone applications for the assessment of active shoulder external rotation*’’, Physiother Theory Pract

[25] Tousignant-Laflanne Y, Boutin N, Dion AM and Vallee CAA, ‘‘ *Reliability and criterion validity of two applications of the iPhone to measure cervical range*’’*, 2013*

[26] Johnson, Linda B, ‘‘*Validity and reliability of smartphone magnetometer based goniometer evaluation of shoulder abduction*’’, Manual Therapy, 2015.

[27] Brian C.Werner, Russell E, and Hozgrefe, ‘‘*Validation of an innovative method of shoulder range of motion measurement using a smartphone clinometer application*’’, University of Virginia

[28] Rafael Dos Santos, Viviane Derhon, Michelle Brandalize and Luciano Rossi, ‘‘*Evaluation of knee range of motion: Correlation between measurements using a UG and smartphone goniometric appliciation*’’, *2016*

[29] ‘‘*Phidgets : Accelerometer Primer*’’ [Online]. Available: http://www.phidgets.com/docs/Accelerometer_Primer#Gravity_vs._Acceleration [Accessed: 26 April 2017]

[30] J.Fisher, Christopher, ‘‘*Using an Accelerometer for Inclination Sensing*’’*, 2016*

[31] Sam Naghshineh, Golafsoun Ameri and Mazdak Zereshki, ‘‘*Human Motion capture using Tri-Axial accelerometers*’’

[32] *‘‘The integration of motion analysis and wearable techonology’’* [Online] Available: https://gunjanpatel.wordpress.com [Accessed: 28 April 2017]

[33] *‘‘Planning Algorithms’’* [Online]. Available: http://planning.cs.uiuc.edu/node102.html [Accessed: 28 April 2017]

[34] *‘‘How GAP and GATT Work’’* [Online]. Available: https://punchthrough.com/bean/docs/guides/everything-else/how-gap-and-gatt-work/#generic-attribute-profile-gatt [Accessed: 1 May 2017]

[35] *‘‘Bluetooth smart: GATT’’* [Online]. Available: https://learn.adafruit.com/introduction-to-bluetooth-low-energy/gatt. [Accessed: 1 May 2017]

[36] ‘‘*A multi-faceted language for the Java platfrom*’’ [Online]. Available: http://groovy-lang.org [Accessed: 8 April2017]

[37] ‘‘*Gradle Build Tool 3.5*’’ [Online] Available : https://docs.gradle.org/current/userguide/writing_build_scripts.html [Accessed: 8 April 2017]

[38] ‘‘*Java Powers Our Digital World*’’ [Online]. Available : https://www.go.java/index.html?intcmp=gojava-banner-%20java-com [Accessed: 9 April 2017]

[39] ‘‘*Sugar ORM*’’. [Online]. Available : https://www.github.com/chennaione/sugar [Accessed: 5 May 2017]

[40] ‘‘*Some Custome Controls for Android*’’ [Online] Available :
https://www.github.com/sanmeranam/CustomeControl/blob/master/README.md
[Accessed: 3 May 2017]
[41] ‘‘*List Fragment*’’ [Online] Available :
https://www.developer.android.com/reference/android/app/ListFragment.html
[Accessed: 3 May 2017]
[42] ‘‘*GATT Descriptors*’’ [Online] Available :
https://www.bluetooth.com/specifications/gatt/descriptors [Accessed: 4 May 2017]
[43] ‘‘*Qt Documentation*’’ [Online] Available :
http://www.doc.qt.io/qt-4.8/designer-using-a-ui-file.html [Accessed: 4 May 2017]